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Procedia Engineering 97 (2014) 1667 – 1675

**Procedia  
Engineering**[www.elsevier.com/locate/procedia](http://www.elsevier.com/locate/procedia)

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

## Experimental Analysis of Hybrid Nanofluid as a Coolant

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### Abstract

Investigation of heat transfer behaviour of hybrid nanofluid (HyNF) flow through the tubular heat exchanger was experimentally studied. In this analysis, the effects of thermal characteristics of forced convection, thermal conductivity and heat transfer coefficient were explored. The nanofluid was prepared by dispersing the copper-titanium hybrid nanocomposite (HyNC) in the water. The experiments were performed for various nanoparticle volume concentrations added in the base fluid ranging from 0.1% to 1.0%. The results showed that the convective heat transfer coefficient was found maximum by 48.4% up to 0.7% volume concentration of HyNC.

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Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

**Keywords:** Heat transfer coefficient; Hybrid nanocomposite; Nanofluids; Thermal conductivity;

### 1. Introduction

In recent years, the conventional heat transfer fluid was replaced by advanced fluid such as nanofluid due to its better heat transfer characteristics and flow characteristics. The application of nanofluids in the thermal management systems brings out not only the better heat transfer and also it reduces the size of the heat exchangers. Recently some of the authors investigated the performance of heat exchangers by the application of nanofluids. The thermal conductivity of nanofluids is one of the reasons for the enhancement of heat transfer. Sundar et al. [1] investigated the thermal conductivity of  $\text{Al}_2\text{O}_3$  and  $\text{CuO}$  nanofluids experimentally. The results showed the thermal conductivity enhancement from 9.8% to 17.89% for  $\text{Al}_2\text{O}_3$ , and 15.6% to 24.56% for  $\text{CuO}$  nanofluids in the temperature range from 15 °C to 50 °C at 0.8% volume concentration, compared to the base fluid. Sharma et al. [2] conducted studies in the silver nanoparticles in the colloidal phase. The stability as well as thermal conductivity of these nanofluids was determined with a transient hot-wires apparatus. Madhesh et al. [3] carried out investigation in the heat transfer potential and rheological characteristics of copper–titanium hybrid nanofluids (HyNF) using a tubular heat exchanger.

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The nanofluids were prepared by dispersing the copper–titania hybrid nanocomposite (HyNC) in the base fluid, ranging from 0.1 vol. % to 2.0 vol. % concentration. The heat transfer and rheological characteristics of nanofluids containing HyNC of an averaged size of 55 nm were experimentally analyzed. The test results showed that the Nusselt number, convective heat transfer coefficient, and overall heat transfer coefficient were increased by 49%, 52% and 68% respectively, up to 1.0% volume concentration of HyNC.

Abareshi et al. [4] synthesized magnetite  $\text{Fe}_3\text{O}_4$  nanoparticles by co-precipitation method at different pH values. The results showed that the shape of the particles is cubic and they were super paramagnetic at room temperature. To prepare the magnetic nanofluids,  $\text{Fe}_3\text{O}_4$  nanoparticles were dispersed in water with the presence of tetramethyl ammonium hydroxide as a dispersant. The thermal conductivity measurements were conducted by varying the temperature and concentration. The results revealed that the increase in temperature and concentration increases the thermal conductivity ratio. Utomo et al. [5] investigated the viscosity, heat transfer coefficient and thermal conductivity of alumina and titania nanofluids.

From the literature survey, it is seen that very few works were presented in the hybrid nanofluid and the composite such as Cu-TiO<sub>2</sub> suspended in the cold fluid. Madhesh et al. [6] conducted experiments in heat transfer and flow characteristics of silver (Ag) Ethylene glycol (EG) nanofluids. The results revealed that very low concentration of nanoparticles in the base fluid which organized the mean free path available for particles moving between the inner fluids layers could promote the heat transfer effectively.

## Nomenclature

A	surface area, m <sup>2</sup>
C	specific heat capacity, J/ (kg K)
D	inner tube diameter, m
L	length of the tube, m
h	convective heat transfer coefficient, W/(m <sup>2</sup> K)
K	thermal conductivity, W/ (m K)
m	mass flow rate, kg/s
Re	Reynolds number
Nu	Nusselt number
Pr	Prandtl number
v	volume, m <sup>3</sup>
Q	heat transfer rate, W
Q <sub>ave</sub>	average heat transfer rate, W
T	temperature, K
T <sub>(mean)</sub>	bulk temperature of the nanofluid, K
T <sub>wall</sub>	average temperature of the wall, K
$\Delta T_{lm}$	logarithmic mean temperature difference, K
o	outside
out	outlet
p	nanoparticle

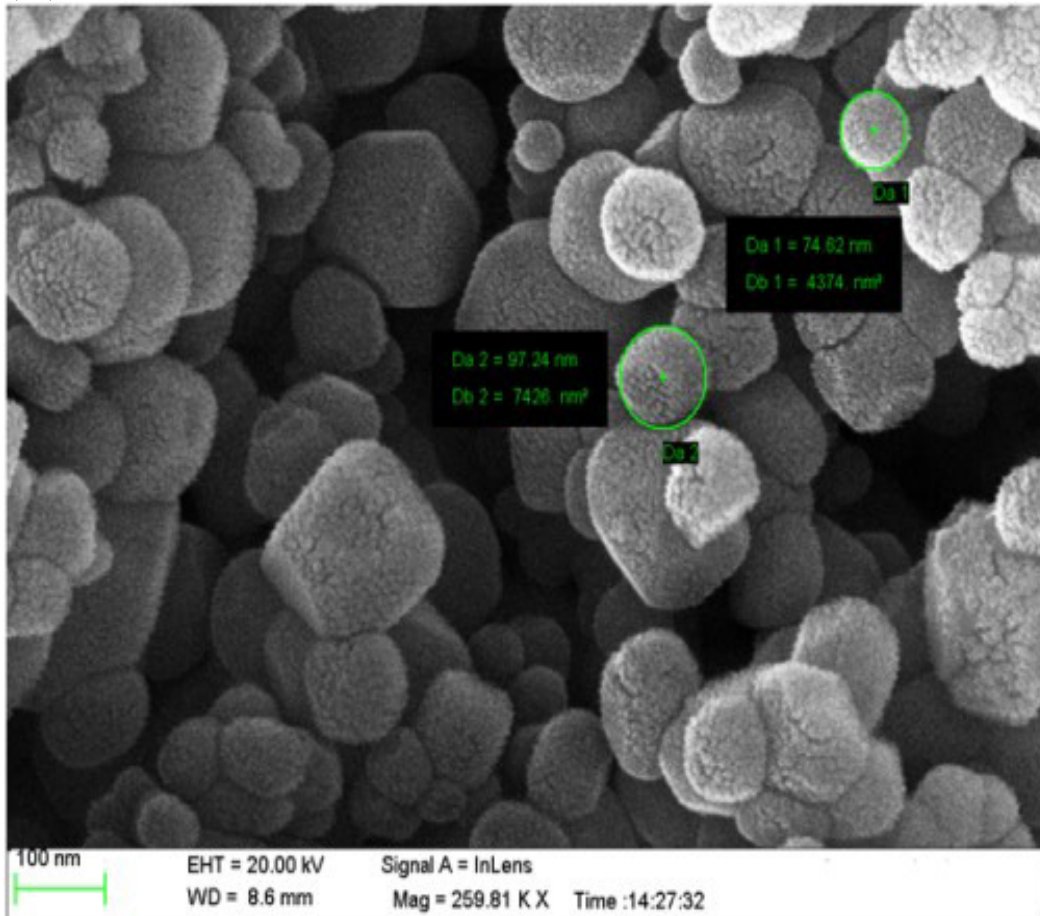
## 2. Experimentation

### 2.1. Preparation method of Hybrid nanofluids

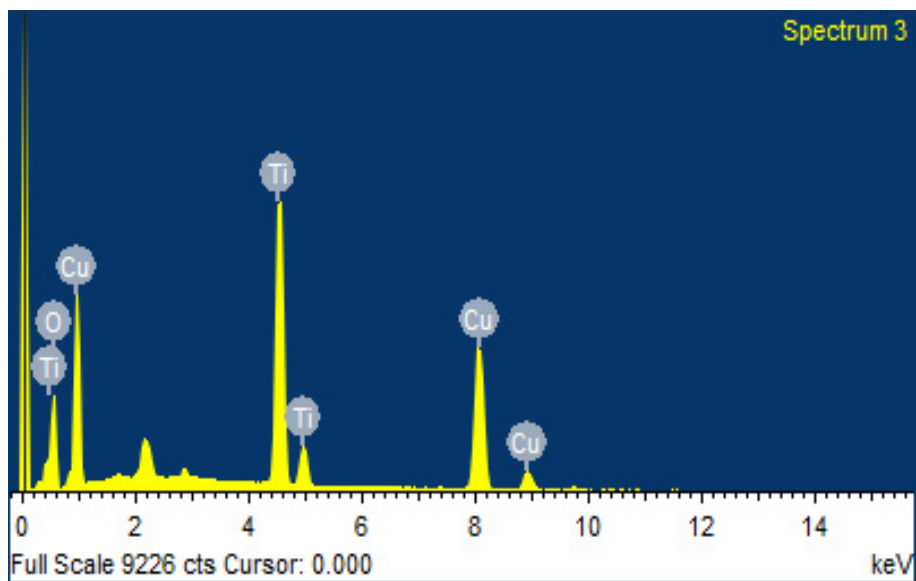
The facile preparation of the copper/titania hybrid nanocomposite (HyNC) consisted of the following steps: (1) ultrasonic dispersion of an aqueous solution containing titania (5 g), (2) intense stirring and mixing of a copper

acetate (0.5 g) aqueous solution, containing ascorbic acid and sodium borohydride reducing agents with the prepared titania aqueous solution, for 2 hours at 45°C and ambient pressure, for subsequent production of HyNC colloids, (3) washing and filtration of the HyNC colloids followed by vacuum drying, (4) ultrasonic re-dispersion of the as-prepared HyNC powder into the base fluid, in volume concentrations ranging from 0.1% to 1.0% using the ultrasonic vibrator (UP200S-Hielscher).

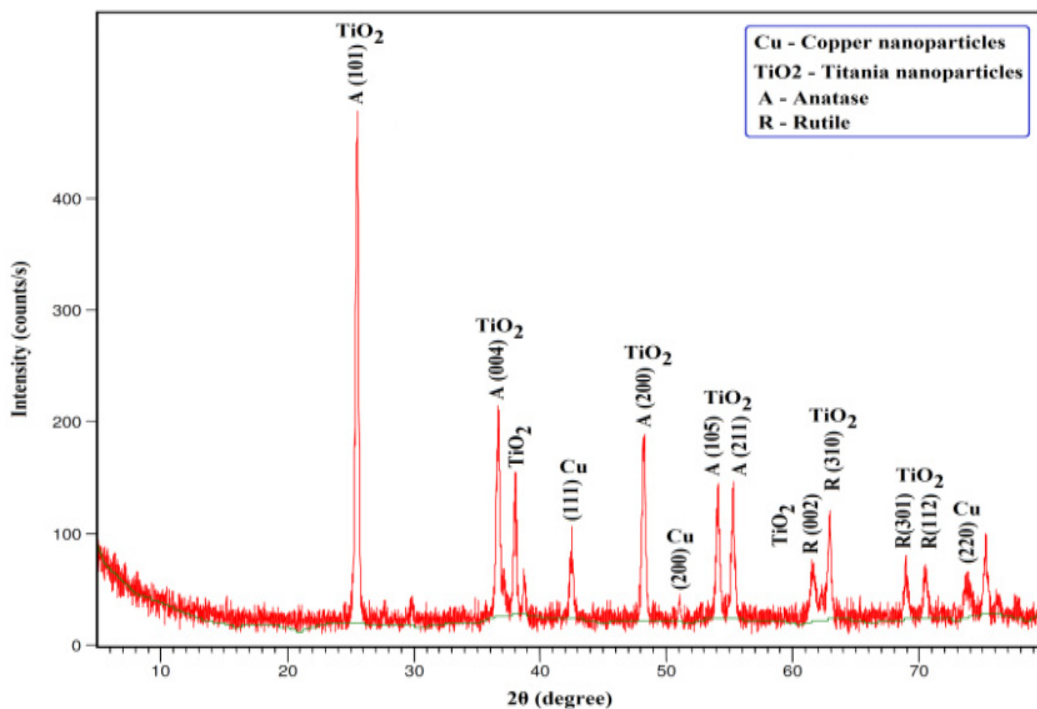
The surface morphology of the Cu-TiO<sub>2</sub> nanocomposite was examined by a high resolution field emission scanning electron microscope (FESEM: SUPRA®55, Carl Zeiss, Germany, Electron high tension (EHT): 20 kV). The composition of the Cu-TiO<sub>2</sub> nanocomposite was measured by the EDAX analysis, and the crystallite size and structure of the Cu-TiO<sub>2</sub> nanocomposite was measured by the XRD analysis characterization techniques, as shown in Fig. 1(a-c).



(1)



(b)



(c)

Fig. 1. (a) FESEM image of as synthesized Cu-TiO<sub>2</sub> nanocomposite, (b) EDAX and (c) XRD pattern of Cu-TiO<sub>2</sub> nanocomposite.

## 2.2. Experimental system description

The experimental system consist of two sets of constant temperature bath are provided in this experimental setup which consists of vapour compression refrigeration system with electrical heater and stirrer. The test section was the horizontal concentric tubes of length 1.8m, 1mm tube thickness; outer diameters of inner and outer tubes are 6.4mm and 12.7mm respectively. To minimize the leakages the test section was well insulated with glass wool. The HyNF kept in a separated cold water container with the provision of electric heating facility of 1.0KW along with proportional-integral-derivative controller (PID). For an accurate measurement of HyNF, a Coriolis type mass flow meter with  $\pm 0.1\%$  accuracy was used to measure the flow rate. The cooling capacity of the constant temperature bath was controlled by a 2.0 TR (Ton of Refrigeration). The cold water tank contains 1500 rpm stirrer which was used to obtain uniform temperature. All fluid circulating tubes are well insulated to reduce the heat dissipation.

## 2.3. Experimental Procedure

Prior to each experiment, the tube in tube heat exchanger was cleaned with acetone to remove any contamination. Experiments were carried out for the mass flow rates ranging from 0.023Kg/s to 0.078 Kg/s to determine the Reynolds number, Nusselt number, convective heat transfer coefficient. The inlet temperature of the hot fluid at 30°C was allowed to flow through the outer copper tube and the cold HyNF temperature at 2°C was made to flow through the inner copper tube. The counter flow configuration tends to attribute the overall effectiveness of the heat exchanger. The K-type thermocouples were used to measure the bulk and tube wall temperatures. The thermocouples were spaced evenly and were located 36cm apart. In order to measure the cold water and the hot nanofluid temperatures, K-type thermocouples were inserted into the inlet and outlet sections of the tube, the wall of the tube, and the hot and the cold fluid reservoir as well. The experimental system was well insulated, fully instrumented with sensors and transducers, and the output from the DC power supply was interfaced to a data acquisition system (Agilent 34972A) in conjunction with the centralized controlling unit. The pressure drop ( $\Delta P$ ) in the test sections, was measured by using a differential pressure transducer. The temperatures at the inlet, outlet and the wall of the tube sections, the flow rate, and pressure difference of the nanofluids flowing through the test section were measured and recorded throughout the experimentation.

The sensed signals corresponding to the parametric variables including temperature, pressure and flow rate were measured and processed by the data logging/centralized controlling unit.

The as- prepared Cu-TiO<sub>2</sub> nanocomposite was re-dispersed in the base fluid (de-ionized double distilled water from the Millipore distiller) using UP200S-Hielscher ultrasonicator, to prevent uncontrolled agglomeration of powders due to intermolecular forces of attraction. The thermal conductivity of HyNF was measured using the NETZSCH LFA 447 NanoFlash equipment. The accuracy of the equipment was  $\pm 3\%$  and its range of thermal conductivity measurement varied from 0.1W/m K to 2000W/m K.

By varying the volumetric concentrations of the as prepared Cu-TiO<sub>2</sub> nanoparticles in base fluid ranging from 0.1% to 1.0 %, the heat transfer potential of the proposed heat exchanger was investigated.

## 3. Results and discussion

### 3.1. Efficient Morphology and surface composition of HyNC

The results of the FESEM image Fig. 1 (a) clearly showed the formation of copper nanoparticles on the surface of titania nanoparticles which formed the required hybrid nanocomposite. In addition, the energy dispersive X-ray (EDAX) spectrum Fig. 1 (b) provided more information in determining the mode of assembly of Cu-TiO<sub>2</sub> composite

nanoparticles that sturdily supported the interpretation from the FESEM result. The peaks in the spectrum vindicated the formation of copper and titania in the as-prepared hybrid nanocomposite. The strong peaks obtained in the spectra suggested the pattern of highly crystalline copper nanoparticles on the surface of the titania nanoparticles.

The XRD peaks confirmed the formation of copper-titania hybrid nanocomposite particles in terms of intense and sharp Bragg reflections ( $2\theta^\circ$ ) exhibited, which were indexed to the corresponding lattice planes, as shown in Fig. 1(c). The weight proportions of titania to copper precursor played an active role in creating nucleation sites for the reduction of copper ions to occur on its surface. The sharp peaks obtained due to scattering at interplanar spacing were attributed primarily to the anatase phase of titania, and the copper nanoparticles thus formed on its surface were highly crystalline, with a dominant (111) face centered cubic (FCC) structure as well.

The XRD patterns revealed that, for the hybrid nanocomposites the intensity peaks obtained at the (111), (200), and (220) planes were pragmatic to be in good agreement with the JCPDS standards [7]. The average crystallite size obtained using the Debye-Scherrer method [8] was found to be 55nm, which agreed well with the FESEM measurements.

### 3.2. Experimental apparatus validation

The present experimental system was validated using de-ionized water flowing through the tubular heat exchanger with the well known existing Dittus and Boelter correlation [9]. The Fig. 2 shows that there was an increase in the ratio of Nusselt and Prandtl number with respect to the Reynolds number and at the same time the experimental results produced the same trend existing in the Dittus- Boelter correlation for Nusselt number.

The graph inferred that the experimental results were nearer to the theoretical data for the various range of Reynolds number. The percentage error was depicted as 5% which is shown in the comparative graph.

### 3.3. Thermal conductivity of HyNF

The thermal conductivity of HyNF as a function of the particle volume concentration and temperature is depicted in Fig. 3. The result showed that the thermal conductivity of HyNF increased with the nanocomposite volume concentration and the nanofluid temperature. With the increase of fluid temperature, the movement between the particles increased, raising the thermal conductivity [10]. The probable cause of increase in thermal conductivity of the nanofluids not only depended on particle concentration and temperature, but also due to the influence of other parameters like size and shape. It is usual that the tiny dissimilarity of the trends may perhaps due to the particle configuration and clustering [11].

The copper nanoparticles on the titania surface act as the thermal boundary between the base fluid and the wall surfaces which induced the enhancement of thermal conductivity of nanofluid. The previous literature studies suggested that the titania material is one of the better heat transfer material and economical for the heat transfer applications typically suitable for nanofluid. From this perception, the creation of highly crystalline and heat conductive copper nanoparticles on the surface of titania particles was distinct and significant, which collectively enhanced the capabilities of nanofluids in capturing and dissipating thermal energy from the heat source and dissipating it to the surrounding fluid.

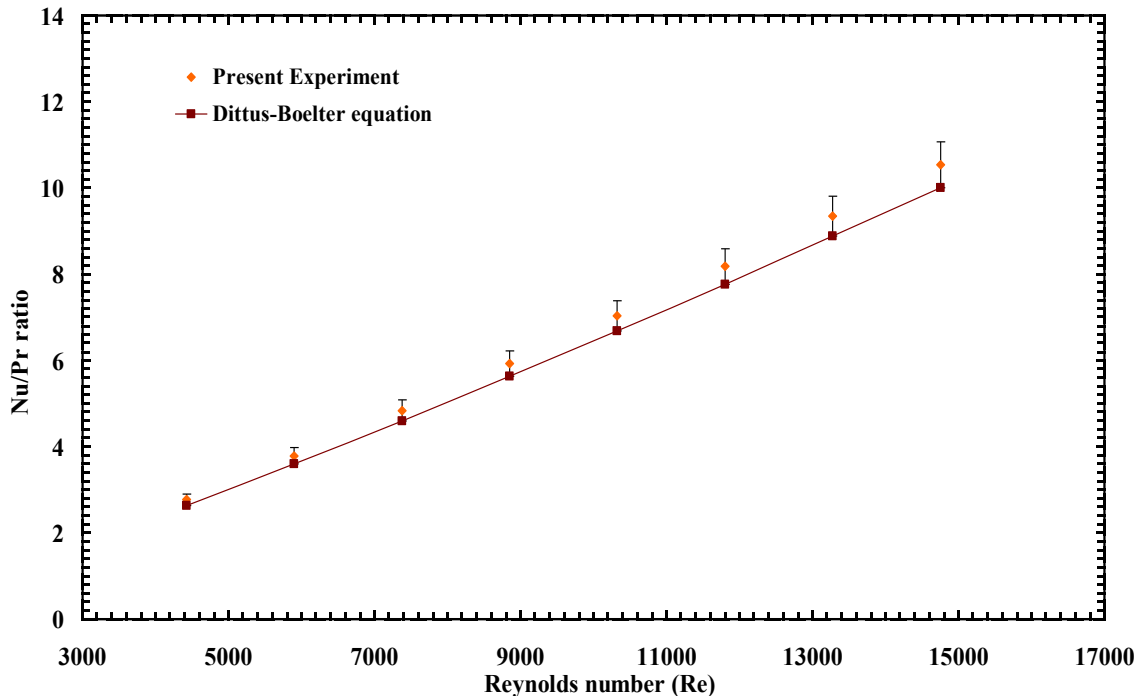


Fig. 2. Comparison of experimental Nusselt number with Dittus –Boelter relation for the base fluid in the turbulent regime.

The addition of nanoparticle concentration of HyNC led to the formation of compactly packed thermal interfaces, which in turn, contributed to accomplish a better thermal conductivity of the nanofluids. This can be considered to be an indispensable factor for utilizing HyNC in the base fluid, as a mean to achieve improved thermophysical characteristics, and the heat transfer potential of nanofluids.

### 3.4. Heat transfer behaviour of HyNF

Variations of convective heat transfer coefficient versus Reynolds numbers for various concentrations of nanoparticles are illustrated in Fig. 4.

Based on the results, it was clear that at the lower volume concentrations of less than 0.7% HyNC nanoparticle, it showed better heat transfer behavior than at the higher volume concentrations of greater than 0.7%. For the lesser particle sizes, the phonon heat transfer was adequate to raise the temperature of the particle to that of heat source [12]. It was seen that the nanoparticles suspended in base fluid increases the heat transfer coefficient even for a very low particle weight fraction of 0.1% and the maximum heat transfer enhancement is obtained for nanofluids with 0.7 vol. % of nanoparticle concentration. At 1.0 vol. % concentration of nanoparticles, compared to the base fluid the heat transfer coefficient was increased from 20.8% to 24.4% for the various ranges of Reynolds number starting from 4315 to 14384. Further, the heat transfer coefficient increased by 48.4% compared to the base fluid at 0.7% volume concentration for the Reynolds number of 4348. The reason for the increase in heat transfer was due to the motion of nanoparticles which caused microconvection in fluid [13]. From this study, it was known that the heat transfer enhancement of nanofluids was more at high Reynolds numbers. The higher values of Reynolds numbers caused turbulence due to the higher velocity of nanoparticles which in turn enhanced the heat transfer. It can be concluded from the figure that other than the thermal conductivity some of the other mechanisms also played the role in enhancement of heat transfer of nanofluids

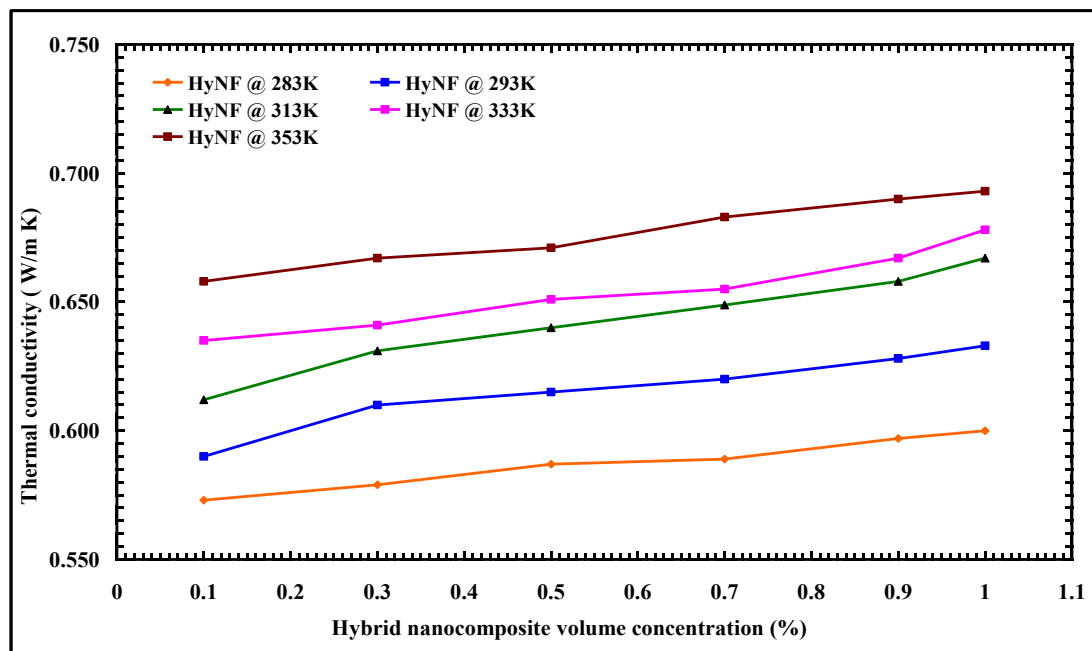


Fig. 3. Variation of thermal conductivity of HyNF with various volume concentration of hybrid nanocomposite

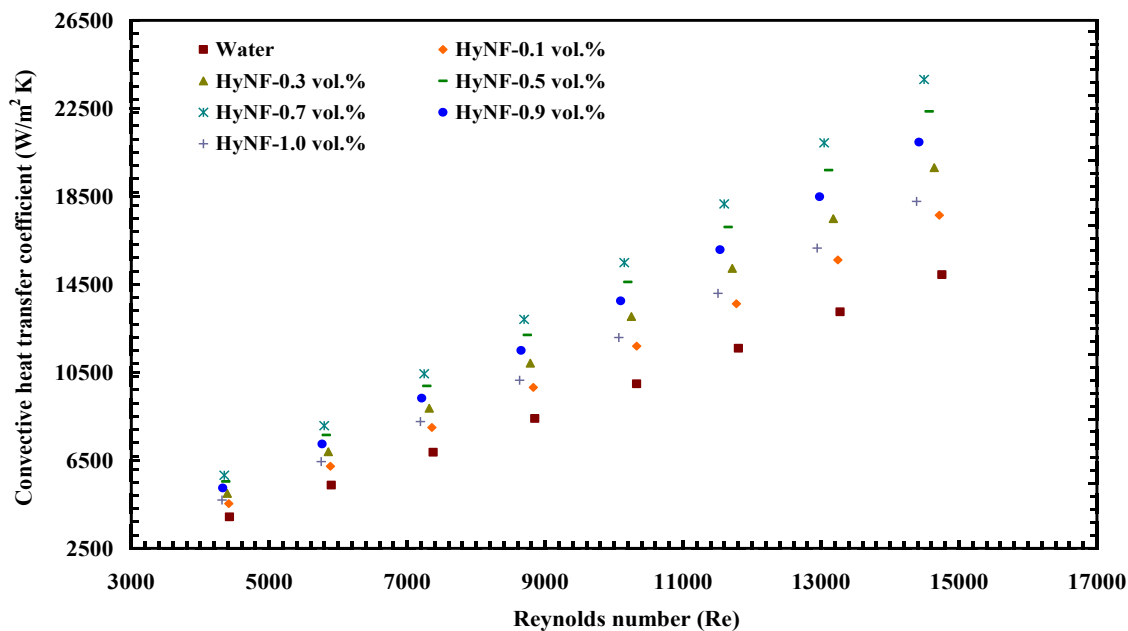


Fig. 4. Variation of convective heat transfer coefficient with Reynolds number



#### 4. Conclusions

In the present study, heat transfer characteristics of HyNF were experimentally investigated using a tube-in-tube counter flow heat exchanger. The experimental analysis performed has led to the following conclusions:

- The surface functionalized and highly crystalline nature of HyNC contributed for creating effective thermal interfaces with the fluid medium; thereby enabled for achieving improved thermal conductivity and heat transfer potential of nanofluids.
- The convective heat transfer coefficient of nanofluids increased with HyNC concentration and Reynolds number. For the volume concentration up to 0.7%, convective heat transfer coefficient of HyNF was enhanced by 48.4%. The effective thermal conductivity and diffusion kinetics of HyNC in the fluid medium paved way for improved heat transfer characteristics of HyNF.

#### Acknowledgements

The authors gratefully acknowledge their indebtedness to the DST, New Delhi, for providing financial support to carry out this research work, under the SERB (DST Sanction order No. SB/EMEQ-285/2013).

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